# The Application of Wireless LANS in Mine Automation

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## 1. INTRODUCTION

The objective of this paper is to provide an overview of mine automation applications, developed at the Queensland Centre for Advanced Technology (QCAT), which make use of IEEE 802.11b wireless local area networks (WLANs). The paper has been prepared for a 2002 conference entitled "Creating the Virtual Enterprise - Leveraging wireless technology within existing business models for corporate advantage". Descriptions of the WLAN components have been omitted here as such details are presented in the accompanying papers.

The structure of the paper is as follows. Application overviews are provided in Sections 2 to 7. Some pertinent strengths and weaknesses are summarised in Section 8. Please refer to http://www.mining-automation.com/ or contact the authors for further information.

## 2. VIDEO SURVEILLANCE

In coal mines, requirements have been stated for video capabilities for surveillance of the Longwall, monitoring transfer points on conveyers, checking for belt rips and fires. In metaliferrous mines, requirements exist for remote surveillance of unsupported roof areas such as stopes.

Our approach is to serve and record discrete video images so that images analyses can be carried out. For example, a three-dimensional mapping of faces and subsequent stability or joint analysis can be provided via a CSIRO developed photogrammetry tool; see http://www.dem.csiro.au/research/ and follow the link to Mine Environment Imaging. In addition, images can be combined into a virtual reality three dimensional world developed by CSIRO and known as the Virtual Mine; see http://www.dem.csiro.au/research/ and follow the link to Mine Engineering.

Video surveillance over local area network (LANs) can involve a mixture of optical fibre, twisted pair and wireless components. If the dominant criteria are distance and bandwidth, then optical fibre is a good choice; see the description of the Numbat mine rescue vehicle in [1]. If the cable to the camera needs to supply power and bear the load, then reinforced twisted pair cable is appropriate. Since the maximum allowed length of twisted pair for 10Base-T is 100m, a pair of HDSL modems are employed for non-line-of-sight communication paths of greater than 100m. A *CISCO* 802.11b access point is used to provide wireless communication from a rotating cable reel (see Figure 1) to a laptop equipped with a *CISCO* 802.11b PC Card.

Firewire (IEEE 1394) cameras and Intel's JPEG library are used to acquire and compress images respectively. A *Strongbow* intertial navigation system (INS) is co-located with the camera so that images can be tagged with position and orientation data.

Many Australian coal mines are *Microsoft* sites. Typically, software deliverables need run on the current version of the *Microsoft Windows* operating system, and data is required to be compatible with *Microsoft SQL Server*. Consequently the applications having user interfaces are often developed using *Microsoft Visual C/C++*.

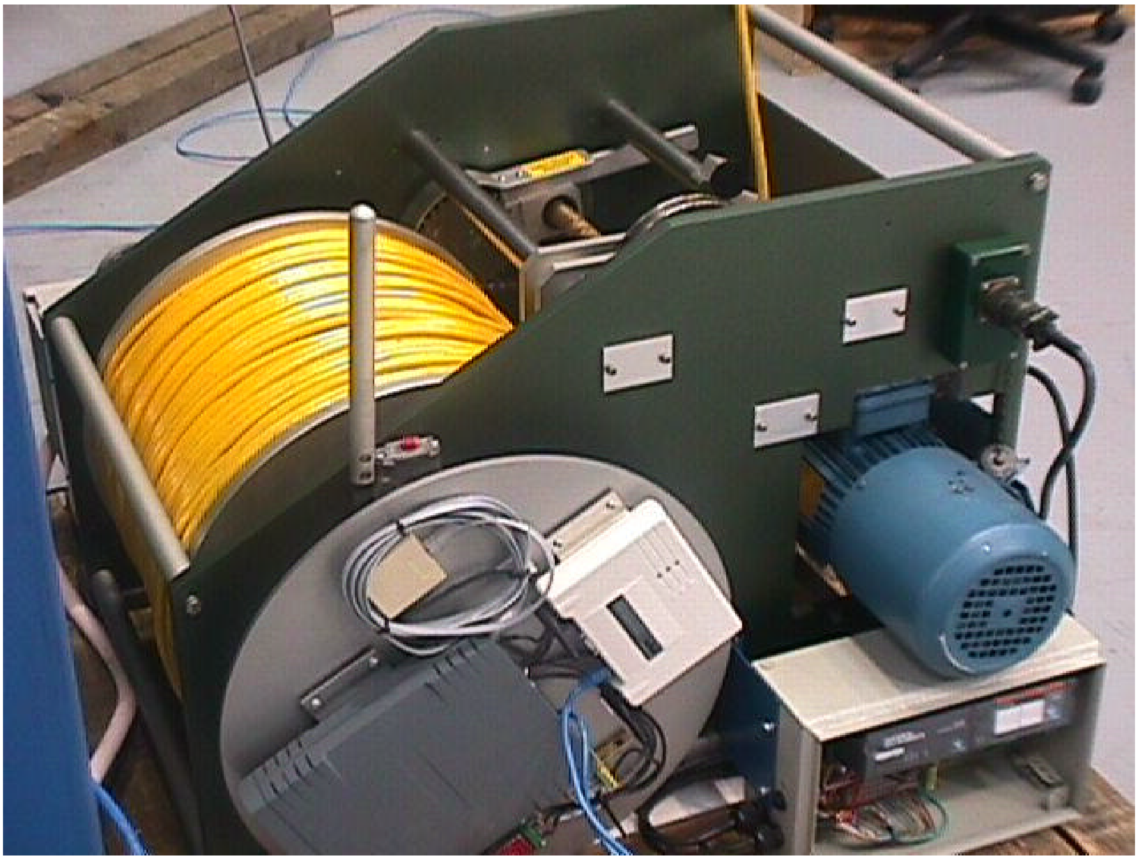

Fig. 1. *CISCO* 802.11b access point connected to a HDSL modem mounted on a rotating cable reel.

## 3. MAVERRIC

The Mobile Adaptive Video Ethernet Router with Reliable I/O Communications (MAVERRIC) system is being developed by CSIRO – Manufacturing and Infrastructure Technology. Conventional video server approaches usually involve an interconnection of commonly available subsystems, such as a server, switch and bridge. There are two problems with this approach. Firstly, the hardware has not been designed for vibrating and high temperature environments. Secondly, the above-mentioned building blocks have not been optimised for mobile applications. In particular, there is no adaptation to the available radio communication bandwidth when communications are poor. This has serious ramifications for mobile control where it is possible for the video server to "flood" the WLAN. This flooding can prevent important control data reaching the mobile platform in a timely manner.

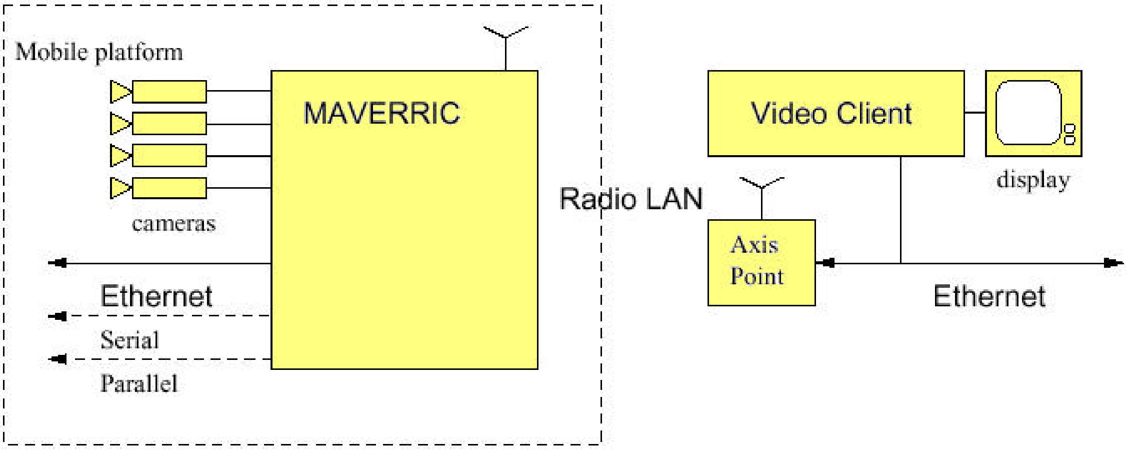

Fig. 2. MAVERRIC system block diagram.

The MAVERRIC approach is a single system replacing the video server, bridge and switch as shown in Figure 2. The system will be configured to give priority to specific channels of data so that when there is a degradation in signal strength, data such as video can be throttled back. It is anticipated that the customer should be able to supply the stationary client server hardware.

## 4. LONGWALL AUTOMATION

The longwall mining process is the most popular method of high-output underground coal mining. A large mining machine called a shearer cuts back and forth across an underground coal panel between parallel service roads typically several hundred metres apart. The shearer travels on a rail structure which incorporates a chain conveyor for moving the extracted coal to the end of the panel from where it is transported to the surface for processing. Large hydraulically powered supports prevent the roof above the extracted coal seam from collapsing onto the shearer and chain conveyor. With each pass of the shearer, the rail structure is incrementally advanced by the powered supports towards the remaining uncut coal seam in a direction orthogonal to the shearer path. The roof behind the advancing supports is left unsupported and collapses into the mined void. A longwall shearer and a portion of the conveyor and powered roof support system is shown in Figure 3.

The longwall mining environment is hazardous for personnel because of the proximity to machinery, falling ground and exposure to explosive mine gases and dust. Presently, miners are required to work in this hazardous environment to control the equipment and ensure the efficient operation of the process. CSIRO is undertaking a major ‘Landmark’ longwall automation project funded by the mining industry through the Australian Coal Association Research Program. The primary objective of this Landmark project is to remove personnel from the hazardous environment.

As part of the automation strategy, CSIRO has introduced new inertial navigation technology to accurately compute the path of the shearer throughout the mining process. A customised military grade inertial navigation sensor is located in a flameproof enclosure on the moving shearer and the shearer three-dimensional position is recorded at each 0.1m of travel.

Maintaining a data communication channel to the moving shearer is difficult due to the harsh environment. The only existing channel is by means of a low-baud serial modem link over the main power supply cable and this is essentially dedicated to high-priority shearer control data.

To facilitate the transfer of the navigation data from the mobile shearer, a *CISCO* Wireless Ethernet Workgroup Bridge is installed within the flameproof enclosure with dual diversity dipole or patch antennae located on a protected external panel on the shearer. Initially, a single *CISCO* Access Point was installed at a fixed location to achieve a point to point link with the shearer. Performance of this link is severely degraded due to poor radio propagation characteristics and the achievable range is limited to approximately 150m. A store and forward protocol is employed to prevent loss of navigation data during periods of radio outage.

Installation of a distributed wireless Ethernet network is presently in progress to achieve uninterrupted communications throughout the full shearing cycle. Initial analysis suggests that this can be achieved with the addition of two or three additional Access Points located along the shearer path.

The successful implementation of a reliable full-coverage wireless Ethernet link to the longwall shearer represents a major advance in this mining application. The availability of Ethernet on the mobile shearer offers the advantages of increased bandwidth, a standardised protocol, and the use of inexpensive COTS (components of the shelf) equipment.

Fig. 3. Longwall shearer.

## 5. RAPID ROADWAY DEVELOPMENT

The Rapid Roadway Development (RRD) project is a joint project that is part of a general Japan-Australia umbrella agreement for investment in productivity-related research projects for the Australian underground coal industry [4]. The project commenced in 1998. The heart of the project is the development of an autonomous conveying/bolting module (ACBM) that consists of an automatic roof and wall (rib) bolting system and a through-conveyor mounted on a mobile platform. This gives the system considerable flexibility in that it can operate between a variety of coal cutting and haulage options. The overall project aims to design, build, and develop systems support and trial the ACBM. The main components include an automatic roof bolting system, the ACBM platform, together with remote and automatic control systems. The automatic bolting system incorporates a stand-alone PLC-based controller that manages the electro-hydraulic bolting control system. It receives high-level commands from the ACBM control system and reports its system status.

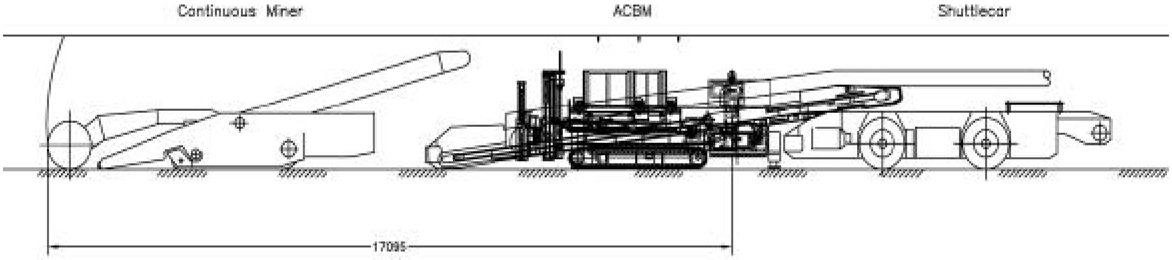

Fig. 4. Sketch of the continuous miner, ACBM and shuttlecar.

Because of the complexity and novelty of the automation subsystems, provision has been made for an ACBM supervisor to be stationed on the machine to monitor status displays and provide manual intervention in the processes when required particularly during the early prototype trial stages.

A key consideration is the sophistication of the remote control system. The simplest solution would be conventional line-of-sight radio remote. Although the operator is located relatively close to the miner (<20m) visibility is generally poor due to the presence of structures between the designated operator station and the miner, as shown in Figure 4. It was decided to develop a complete teleoperation interface incorporating remote vision and displays of other miner-mounted sensor data.

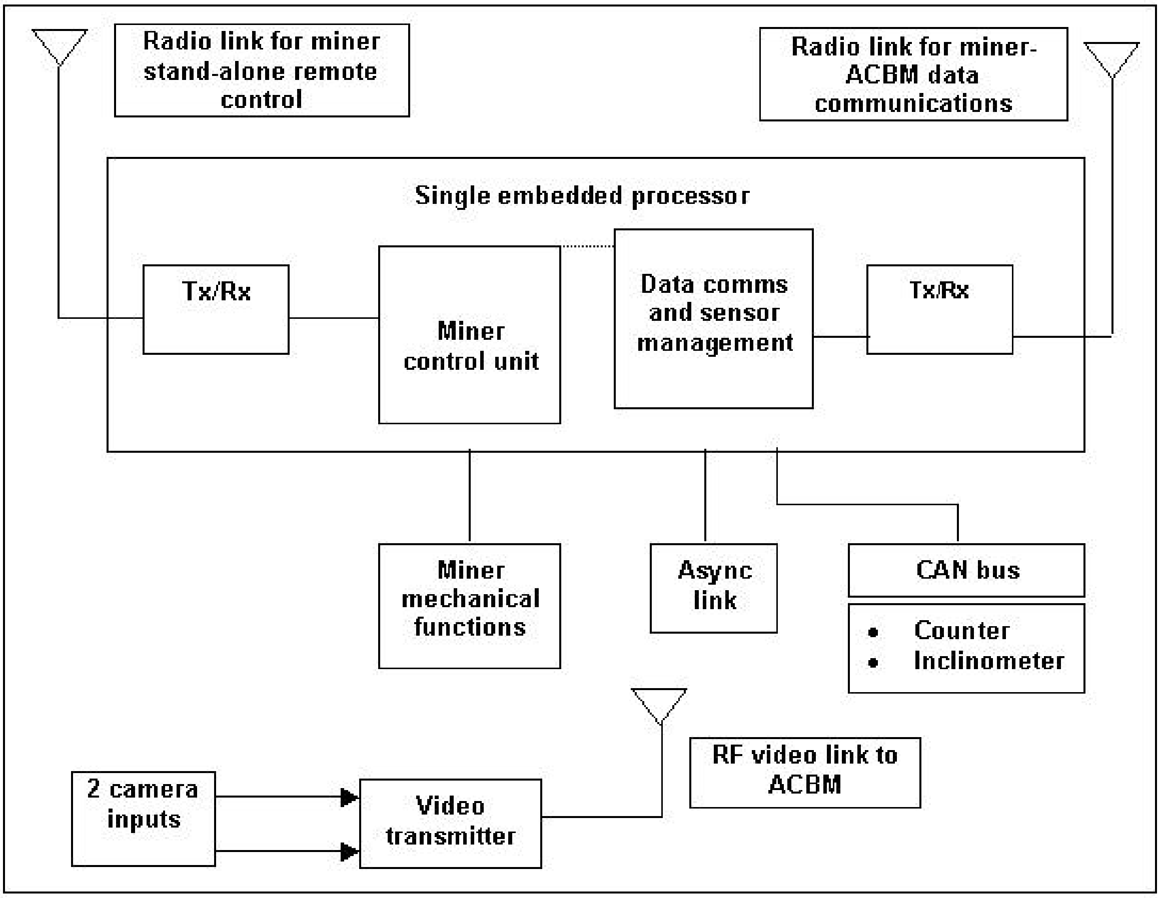

Fig. 5. Block diagram of the ACBM system.

A major input into the design of the miner teleoperation system was the requirement that the miner be able to operate independently and physically separated from the ACBM. This is necessary for maintenance purposes and for some elements of the roadway driveage process. This precluded the use of interconnecting cables between the miner and ACBM, meaning that all video and data transmission would require a radio link. This also required that the teleoperation system would minimise to a conventional radio remote with a portable remote controller for stand-alone operation of the continuous miner. The remote control system is employs *CISCO* 350 series work group bridges and access points. A block diagram of the miner teleoperation and data communications systems is shown in Figure 5.

## 6. AUTONOMOUS UNDERGROUND VEHICLES

Underground mining involves three basic steps: drilling holes, pumping explosives, and finally removing the broken rock. CSIRO is involved in the automation of all of these tasks. Since the platforms that perform these operations are typically mobile, wireless communication to these machines is a prerequisite to automation. Theoretically the existing “leaky feeder” system could be used – but it does not provide the bandwidth, or the flexibility of 802.11b system.

Articulated wheeled vehicles known as Load-Haul-Dump or LHD units are typically used to move (or tram) ore from the stope (open area where rock is blasted) to a crushing plant. The rock stresses in the stope make rock-falls likely, so for safety reasons they are inaccessible to humans.

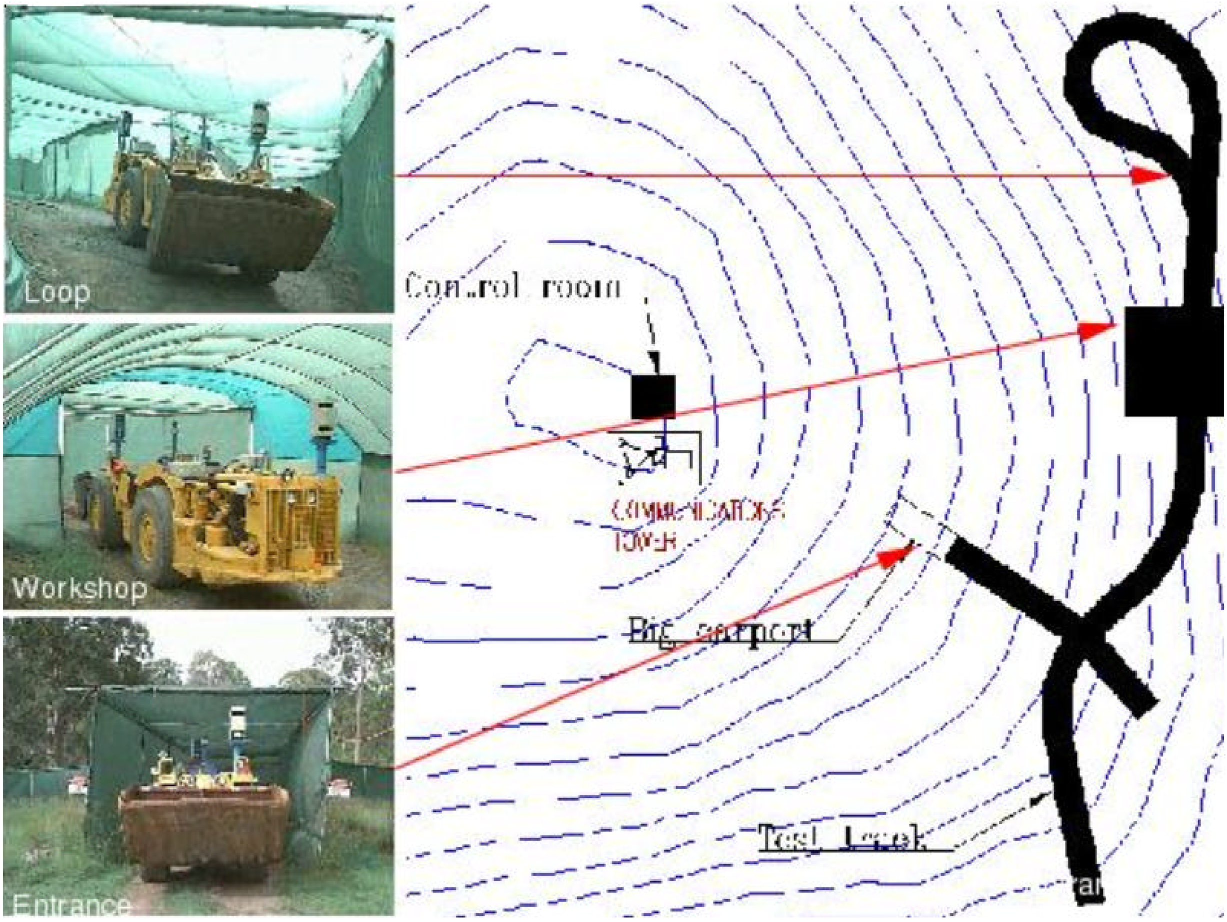

Fig. 6. Mine test facility and automated LHD at QCAT.

Typically, ore ``flows" from a stope to a safe area where it can be collected by a manually controlled LHD. However, at a certain stage of the mining process, it is necessary for the LHD to enter the stope. This is done by tele-remote or line-of-sight remote control of the LHD. In the latter case, this necessitates the driver having to alight the vehicle each cycle which contributes to increased cycle time and the potential for accidents. For these reasons, some mines are now tele-operating the vehicles for the entire cycle. Whilst they have gained in safety, they have often lost productivity compared with manned LHDs. A tele-remote operator is not able to drive the vehicle as fast as a driver on board due to limited remote sensory perception.

The full or partial automation of LHDs is an attractive proposition. There is the potential to increase productivity above tele-remote and remote control levels and to improve safety by removing people from the vehicles altogether. One remote operator could conceivably control or ``manage" a small fleet of largely autonomous LHDs. In fact, the operator need not even be underground at the mine, but could work in an office in a major city.

In July 1998 CSIRO began an industry-funded project (six mining companies and two equipment manufactures) to develop an autonomous navigation system for an LHD. Rather than testing the vehicle underground, an artificial test mine was constructed at QCAT (see Figure 6). The cloth material to cover the walls was chosen because it is opaque to the lasers (the sensor used to navigate the vehicle) but transparent to radio frequencies. Thus it was possible to communicate with the vehicle using a single 802.11b access point.

In 1999, the LHD was driven at full-speed under full automation (no operator input). This project is currently being commercialized by *Caterpillar Elphinstone*, through its joint venture company, *Dynamic Automation Systems*. As part of their installation they are fitting 802.11b axis points into selected zones of two working mines in Australia.

## 7. EXPLOSIVE CHARGING

Another task that can be automated underground is the task of charging (filling) drilled holes with explosives. The explosive material is a liquid emulsion that is pumped into holes that are previously drilled into the roof and/or floor of the tunnel. In 2001, *ORICA* sponsored CSIRO to build a prototype automation system that could automatically find and insert a tube into holes in a simulated rock wall (see Figure 7). As with the LHD, communication with the machine was achieved with 802.11b Ethernet. The machine was remotely instructed to find holes with SOAP (Simple Object Application Protocol) requests.

A number of components from this system are currently being merged into an overseas project called ELAP – Emulsion Loading Automation Projects. ELAP intend to develop a commercial system that will be controlled from the surface with 802.11b Ethernet standard. This will provide full motion video, and will allow operators to find and load blast holes automatically [5].

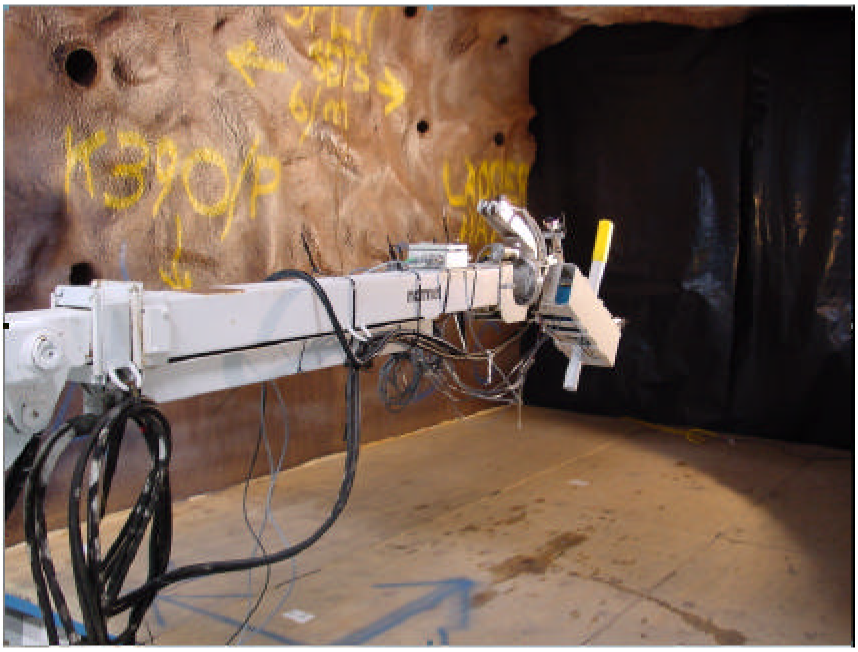

Fig. 7. Prototype automated explosive charging system.

## 8. CONCLUSIONS

The applications of 802.11b wireless technology to recent mine automation projects have been discussed. Some conclusions arising from these applications are itemised below.

### 8.1 **Potential weaknesses**

### *8.1.1 Electromagnetic compatibility / electromagnetic interference (EMC/EMI)*

The best thing about 802.11b WLANs is that they use unlicensed spectrum. The worst thing about 802.11b WLANs is that they use unlicensed spectrum. From an EMC/EMI perspective, the WLANs are expected to be less troublesome in remote rural locations, such as mines, where population densities and competition for spectrum are likely to be minimal. The sources of radio interference can include other equipment and other wireless networks. For example, in some dense areas of the Sydney CBD, degradations in WLAN performance have been reported.

Remote sites are less susceptible to urban interferences for two reasons. Firstly, the received signal power attenuation varies inversely with the square of the distance from the transmitter (in free space), i.e.

$$P_r = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r P_t ,$$

where $\lambda$ is the wavelength, $d$ is the distance, $G_t$ is the gain of the transmitting antenna in the direction of the receiving antenna, $G_r$ is the gain of the receiving antenna in the direction of the transmitting antenna and $P_t$ is the transmitter power [6]. Secondly, the propagation loss increases rapidly when line-of-sight is obstructed [7]; for example, the radio horizon distance in km from a height $h$ in m is given approximately by

$$d = 4.124\sqrt{2h}\,.$$

Typically if the transmitter is sufficiently beyond the radio horizon then interference at 2.4 GHz is not expected to be a problem.

Solving electromagnetic compatibility and interference problems must be undertaken cooperatively. Within remote sites, policies can be instituted to minimise the likelihood of interference. For example, at the *Queensland Centre for Advanced Technologies*, the use of *Bluetooth* (which employs the same unlicensed 2.4 GHZ band) is discouraged. However within shared urban environments there is no guarantee that the spectrum shall remain sufficiently uncommitted. An analogy is the legality of constructing new apartment buildings which obstruct previous unencumbered views. Clearly it is important to be cognisant of the prevailing EMC/EMI risks when investing in WLAN infrastructure.

### *8.1.2 Managing the coverage window*

An obvious advantage of WLANs is the ability to support mobile applications. However the quality of service can vary with the local conditions such as: temporary obstructions that prevent line-of-sight paths, multi-path interference due to the proximity of conductive structures and signal attenuation or fading due to lossy apertures. Numerous error correction systems already exist within the various communication layers. For example, the *CISCO* 802.11b access points have two antennas to mitigate multi-path and employ direct sequence to mitigate frequency selective fading. Further, the TCP/IP protocol involves sending acknowledgements and requires that packets are automatically resent if acknowledgements are not received [8].

In addition, the application designer must manage the window of coverage. In the case of serving video images, UDP is often employed, so that bandwidth is conserved by not resending corrupted (and dated) data. In the Longwall Automation project, the data to be communicated is stored until a window of opportunity occurs. This so-called *store and forward* approach is common to low-earth-orbit satellite communications such as *Iridium*.

### *8.1.3 Planning, maintenance, redundancy and congestion*

As standalone applications migrate to wireless Ethernet, the change from autonomous existence to shared networks must be well managed. Establishing a new highway invariably results in the risk of traffic congestion. The usual requirements of establishing spare capacity for priority traffic, redundancy and future growth remain.

### *8.1.4 Fail-safety*

Fail-safety is a prerequisite for many equipment control applications. Briefly, fail-safe systems are required to put the controlled equipment into a safe stable state when failures (e.g. in power, communications or operating procedures) occur. A conventional 802.11b WLAN system, in isolation, does not meet standards (eg DIN V 19250, PrEn954, AS/NZ 4240:1994) for fail safe remote control of equipment.

### *8.1.5 Matching technology to the application*

Mine managers are pragmatic and business focussed. In particular, they tend to have a good understanding of the economics of processes and cost benefits. Their primary concerns are improvements in productivity and safety. Thus vendors seeking to develop new business in the mining marketplace must understand these applications. Needless to say, the introduction of new wireless technology *per se* is unlikely to reap any benefits. Rather, it is integrated systems that mesh well with existing infrastructure which are needed. There are many processes from the mine face to the mill that are ripe for improvement and even optimisation. A collaborative effort is required from business leaders, research providers, vendors and mine personnel to achieve the desired improvements.

## 8.2 **Strengths and opportunities**

### *8.2.1 Open standards and protocols*

A short-coming of many existing mine equipment communications systems is that the data interfaces are proprietary. The use of proprietary interfaces tends to lock mines into a particular vendor. This precludes the participation of mine staff, third party contractors and vendors in ongoing expansion and maintenance activities. Proprietary systems can be expensive. For example, the costs of mine-wide SCADA-based and leaker-feeder-based software management systems can exceed $5M and $20M respectively.

Different systems sourced from competing vendors are often not interoperable. Consequently mines tend to install multiple systems in parallel. For example, the bulk of mine equipment monitoring is handled by SCADA systems, video is provided by separate CCTV systems, a mixture of DAC intercom, analog telephone and leaky feeder systems support voice communications, and, tube bundle systems are usually employed for mine-wide gas monitoring.

In contrast, Ethernet LANs and WLANs are open systems, which can in principle support a wide range of applications. In general, integrated systems are preferable to disparate applications co-existing on the same platforms. Increasingly mines desire to select interchangeable systems from different manufacturers and vendors, depending on the application, performance, reliability and support. It follows that a key for successful integration is a common protocol. There are numerous application layer protocols for transporting sensor and equipment data over Ethernet. These include Modbus/TCP, Ethernet/IP (or CIP), Profibus on Ethernet and Foundation Fieldbus High Speed Ethernet (see [8] and the links therein).

Subject to managing EMC/EMI, coverage, congestion, redundancy, fail-safety, matching the technology, and, integration, there are opportunities for the application of WLANs in mining industry applications, including: sensor monitoring; equipment control; personal communications, and video surveillance. These are summarised below.

### *8.2.2 Sensor monitoring*

The process control industry is migrating from serial (i.e. RS-232, RS-495) to Ethernet (i.e. IEEE 802.3, 802.11b) networks. WLANs feature ubiquitously in urban organisations. Certainly the above-ground Ethernet technology is mature and standardised (IEEE 802.3 was ratified in 1980). The legacy technology that is conventionally disposed in underground mines is severely bandwidth limited and lacks interoperability with other systems. Many equipment suppliers and vendors have commenced migrating their products and services to Ethernet systems.

The uptake of ethernet by mines has been slow for various reasons. Unprotected cables, connectors and housings borne out of pristine environments will not survive in mines. The intrinsic safety (IS) certification for use in hazardous zones is lacking. As mentioned above, for WLANs, the electomagnetic compatibility and interference issues need to be resolved at each installation because they share unlicensed frequency bands, and, the co-existence of multiple subscribers can hamper critical control applications.

Two industrial systems, namely an intrinsically safe (IS) Ethernet switch and an IS Ethernet sensor interface are being developed by CSIRO in support of a *Mine Communication and Information for Real-time Risk Analysis Project*. The industrial Ethernet sensor interface will be compatible with the large range of existing IS current-loop sensors. The development of the industrial switch will allow LANs and WLANs to be implemented in underground mines and thus support Ethernet sensor, equipment, telephony and video applications.

The legacy communication and process control technologies deployed in underground mines tend to be centralised and lack redundancy, whereas Ethernet LANS and WLANs are amenable to being implemented as autonomous subnets. Consequently the increased bandwidth can be accompanied by improved reliability.

### *8.2.3 Equipment control*

Many mine applications exist where platforms require mobility and hard-wired umbilical connections to host computers are impractical. Such applications are potential candidates for WLAN technologies subject to the qualifiers mentioned above. In addition to the examples described herein, other applications include automated dispatching, loading, unloading, stock piling and traffic control.

### *8.2.4 Personnel communications*

Underground mine personnel require voice communications that is sustained during mine emergencies. Mine emergency incidents can be accompanied by a loss of mine power and damage to infrastructure. Thus two important attributes of emergency communications systems are independence of mine power and robustness to failures. An wireless Ethernet network exhibiting these attributes can be established. The network components will need to be installed with battery backups and redundant loop connections. A so-called Spanning-Tree Protocol accommodates multiple paths loops within a network. In the event a network change (such as path failures), the spanning-tree algorithm can automatically reconfigure the network by making use of redundant paths.

Ethernet networks support internet protocol (IP) telephones, also known as voice over IP (VoIP) telephones. VoIP telephones are in use within urban organisations throughout the world. Typically the VoIP telephones are lined powered and connect directly to a RJ-45 wall socket, ethernet hub or switch. An international VoIP standard (H.323) exists and is fully compatible with public networks. The open architecture allows a mix of VoIP phones from different sources to be used, instead of relying on phones from one PBX manufacturer. VoIP telephony can be used over 802.11b equipped laptop, palm and industrial GP-104 computers. A mine trial of VoIP technology for emergency mine communications will be undertaken by CSIRO researchers.

### *8.2.5 Video surveillance*

Video applications have been mentioned explicitly in Sections 2 and 3. It is perhaps not surprising that video is being used routinely within most of our automation applications. In fact a new coal mine has nominated video applications within their top three Ethernet services priorities (after equipment/sensor monitoring and personal communications). International video coding and transmission standards (H.261, H.263) exist. However video streaming must be planned and implemented so that adequate bandwidth remains available for the higher priority tasks. Therefore in critical situations, it is recommended that separate subnets are established for underground video monitoring. A mine trial of video over a network including hardwired and wireless Ethernet components will be undertaken by CSIRO researchers.

## 9. ACKNOWLEDGEMENT

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## 10. REFERENCES

[1] J. C. Ralston and D. W. Hainsworth. “The Numbat: A remotely controlled mine emergency response vehicle”, *Proceedings of the International Conference on Field and Service Robotics*, Canberra, Australia, pp. 48-55, Dec. 1997.

[2] D. C. Reid, D. W. Hainsworth, J. C. Ralston, R. J. McPhee, “Shearer Guidance: A Path Towards Longwall Automation”, *Proceedings of the 1st International Workshop on Robotics for Mining and Underground Applications*: 5 pages. Brisbane, Australia, 2000.

[3] M. S. Kelly, P. Lever, D. W. Hainsworth, H. Gurgenci and R. Dubois, "Longwall Automation: Are We Ready for Success?". *Proceedings of the 3rd International Underground Coal Conference.* Manly, Australia, 2001.

[4] D. W. Hainsworth, D. C. Reid, R. J. McPhee, J. C. Ralston, P. I. Corke and G. Winstanely, “Automation applied to a rapid roadway development system for underground coal mining”, *Proc. Regional Symposium in Computer Applications in the Minerals Industries*, Tampere, Finland, pp. 23 – 32, Sep., 2001.

[5] A. Young, “Project designed to reduce risk to miners”, *Engineering Dimensions*, March 2002.

[6] R. C. Johnson and H. Jasik, *Antenna Engineering Handbook*, 2nd Ed., McGraw-Hill Book Company, p. 1.12, 1984.

[7] H. R. Reed, C. M. Russell, *Ultra High Frequency Propagation*, Chapman and Hall Ltd, 1966, p. 51.

[8] W. R. Stevens, *UNIX Network Programming*, vol. 1, 2nd Ed., Prentice Hall PTR, 1998, pp. 34-38.

[9] P. Sink, "Eight Open Networks and Industrial Ethernet: A Brief Guide To the Pros and Cons for Users and OEMs", *Industrial Ethenet Association* and *Synergetic Micro Systems*, www.industrialethernet.com and www.synergetic.com, Chicago, USA, 2001.